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Estimating the labor-hour requirements of discrete assemblies is often critical to numerous manufacturers because of its usefulness in determining the production cycle time, the costs of products, the performance of employees, and the price quotes to customers. The traditional method does not necessarily provide a fast and realistic estimation because of the time and complexity necessary to develop and estimate pre-specified times and allowances. In this paper, we propose a new procedure that is simpler and faster. First, we present the data requirements and the regression-based procedure to estimate the labor-hour requirements. Next, we show how specific linear and nonlinear regression analyses are used to determine the labor-hour requirements. Our approach bypasses the cumbersome and time-consuming allowances and pre-specified times as much as possible. To illustrate the key features of our procedure, a numerical example is explained throughout this paper.

Introduction

Labor-hour requirements estimation essentially involves the prediction of the amount of time taken to produce a product (i.e., an assembly) in a manufacturing facility. It is probably one of the most important aspects of work measurement. Labor hour prediction is also essential in order to obtain an approximate idea of the price of the product for the purpose of making quotes to customers and is also required while determining the performance efficiency of an employee. In order to keep up with the competitive market of today, it is imperative that companies use simpler and faster methods to predict labor-hour requirements.

In this paper, we propose such a method for the prediction of the labor-hour requirements based on a project with an electronics manufacturer in the Midwest of the Unites States. Currently, the method in use (which is quite traditional in numerous industries) by the manufacturer is as follows 1. Based on work measurement studies, estimate pre-specified times to assemble a product. 2. Construct various allowances such as personal, fatigue, and delay, etc. 3. By multiplying the pre-specified times by the allowances, compute the estimated labor- hour requirements for a product. As the products and the manufacturing processes become more complex, the current method does not necessarily provide a fast and realistic prediction because of the time to develop and estimate pre-specified times and allowances.

In contrast to this traditional method, we propose to rely on past data and regression techniques to estimate the labor hour requirements, bypassing all allowances and pre-specified times as much as possible. A primary reason for this is that the status quo of the traditional estimation procedure is ineffective and inefficient in view of the changing environments (e.g., the government often asks no detailed analysis of the labor-hour requirements any more).

Data Requirements and Estimation Procedure

For our approach, some past data will be required as follows (the data used in this paper is altered from the actual data; hence this paper only serves the purpose of illustrating the procedure developed).

- The composition of the products - the numbers of the five main components in any product as identified by the manufacturer. The nomenclature used here is "pns" where pns stands for the total part numbers of the five main components, i.e., Integrated Chips (ICs), Electromechanical Components, Electrical Parts, Planar Boards, and Fabrication and Assembly.
- The Earned Hours per unit for each product - the total predicted time required to produce the product per unit.
- The Actual Hours per unit for each product - the time actually taken to make the product per unit.

The earned hours for any new product can obtained from a procedure consisting of the following steps:

- Step 1: Create a database for all the products that are currently being produced by the manufacturer. For each item, list out the following - #'s of ICs, electromechanical components, electrical parts; planar boards, fabrication and assembly; earned hours; actual hours.
- Step 2: For a new product, given its composition (no. of ICs, electromechanical parts, electrical parts, planar boards, and fabrication and assembly), compare with the database created. If a close match is found, assign the earned hours of the matched existing product to the new product.
- Step 3: If no close match is found, then use regression analysis to obtain the estimated earned hours based on the five main components data.

Thus far, we have proposed how the earned hours can be assigned to a new product. Recall that the earned hours can be defined as the total predicted time required to manufacture any product per unit while the actual hours is the time actually taken to make the product per unit. Once earned hours obtained from Steps 2 and 3, the actual hours can be estimated via a regression analysis on the earned hours data. Hence, the objective of developing an estimation procedure for labor-hour requirements that is simpler and faster is achieved.

For the subsequent regression analysis, we consider a set of nine products that are produced by the manufacturer. The table 1 presents the details of each product.

Regression Analysis

This section deals with developing regression models between the earned and actual hours, and also between the earned hours and the five major components of a product.

Earned Hours vs. Actual Hours (Linear Regression Analysis)

Given the data set, the next step in the procedure involves the development of the actual prediction equation for the relation between the earned hours and the actual hours. In order to determine the prediction equation between the earned hours and the actual hours, a linear regression model is developed [4]. The software used for the analysis is SAS (Statistical Applications Software).

One of the reasons for developing this model is to obtain a relation between the earned and the actual hours so as to predict the actual hours given the earned hours. For a product, if the earned hours are known, the actual hours can be calculated, giving an indication of how long the product will take to manufacture. The graph of earned hours vs. actual hours in Figure 1 shows that there could possibly be a linear relationship between them. Upon visual examination, it is noticed that a straight line can be drawn to fit the data points, with a reasonable amount of accuracy. The prediction equation is essentially the equation of this regression line. The goodness-of-fit of the model is dependent on the value of it-square. For the regression model of earned hours vs. actual hours, the it-square value is 96.15%.

The parameter estimates gives the values of the coefficients of the variables in the prediction equation for the said regression model. Based on this, the prediction equation for the regression model for actual hours vs. earned hours is as follows -

actual hours = 0.130332 + 0.970466 * earned hours

Table 1. Data set of the 9 products giving all relevant information

Part#	Earned	Actual	pns	ics	ele	emc	pbs	faa
1	2.4260	2.3193	882	36	531	34	14	267
2	0.4328	0.6522	687	37	426	1	19	204
3	0.0936	0.1433	76	13	39	2	1	21
4	0.1175	0.1389	148	1	25	73	4	45
5	0.4960	0.5500	686	69	466	1	16	134
6	0.3603	0.6300	370	19	317	5	5	24
7	0.3996	0.4950	366	34	265	0	13	54
8	1.3511	1.7278	770	45	460	7	20	238
9	0.2311	0.2500	202	32	108	5	5	52

The dependent variable here is actual hours. The output also lists out the predicted values of actual hours. The variation of the predicted values from the actual ones is not much and hence this is a good regression model to predict the actual hours given the earned hours for any product, made by the manufacturer. Furthermore we have the following observation to make - with respect to the nine products considered, the difference between the earned hours and the predicted actual hours is as in Table 2.

The regression model that is developed between the earned hours and the actual hours can be used in order to estimate the actual hours. Simply, given an estimate of the earned hours, the actual hours can be predicted for any product. The estimate of the earned hours is obtained for the conventional methods used for its determination.

Figure 1. Predicted vs. Actual Values

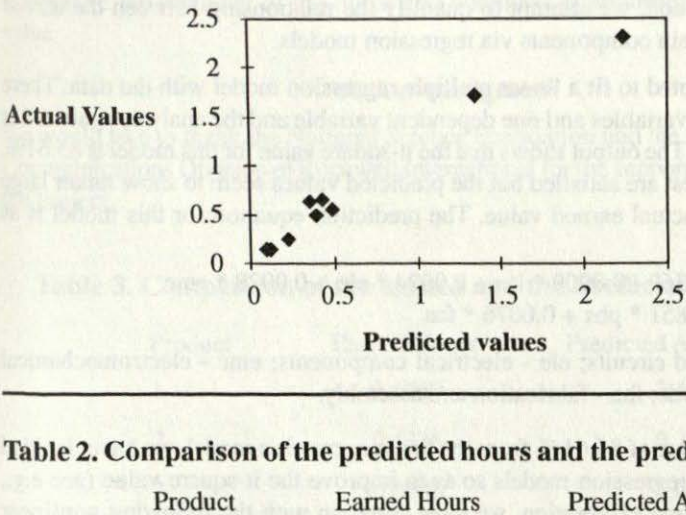

Table 2. Comparison of the predicted hours and the predicted actual hours

Product	Earned Hours	Predicted Actual Hours
1	2.3193	2.4847
2	0.6522	0.5503
3	0.1433	0.2212
4	0.1389	0.2444
5	0.5500	0.6117
6	0.6300	0.4800
7	0.4950	0.5181
8	1.7278	1.4415
9	0.2500	0.3546

Earned Hours vs. Composition of the Product (Multiple Regression Analysis)

Thus far, we have examined the relationship between the earned hours and the actual hours. We will now examine how the earned hours can be predicted given the composition of the products.

The composition of the product or the product complexity is represented by the numbers of the five main components that make up many of the products produced by the electronics manufacturer. The term product complexity also represents the complexity of the design of a product. The five components are the ICs, electromechanical parts, electrical parts, planar boards, and fabrication and assembly.

It has been the empirical experience of the manufacturer that the amount of time to be taken for a product or the earned hours is directly related to the complexity of the design. The more complex the design of the product, the longer it will take to manufacture it. Hence, in this section, we attempt to quantify the relationship between the earned hours and the five main components via regression models.

First, we have attempted to fit a linear multiple regression model with the data. There are five independent variables and one dependent variable and the analysis again relies on the SAS software. The output shows that the it-square value for this model is 85.61%. The F test and the t test are satisfied but the predicted values seem to show rather large variations from the actual earned value. The prediction equation for this model is as follows:

$$\text{earned hours} = -0.0360 - 0.0009 * \text{ics} + 0.0024 * \text{ele} + 0.0028 * \text{emc} - 0.0851 * \text{pbs} + 0.0076 * \text{faa}$$

where ics - integrated circuits; ele - electrical components; emc - electromechanical parts; pbs planar boards; faa - fabrication and assembly.

With the R-square value of 85.61 % from the linear regression model, we have decided to explore nonlinear regression models so as to improve the it-square value (see e.g., [3] and [5]). After some exploration, we have come up with the following nonlinear relation that results in 95.41% R-square value:

$$\text{earned hours} = -0.593 + 0.1127 * \text{ics} - 0.0014 * \text{ics2} - 0.0122 * \text{ele} + 0.000031 * \text{ele2} + 0.0164 * \text{emc} + 0.0264 * \text{pbs} - 0.0091 * \text{faa}$$

where ele2 = ele * ele - electrical components; ics2 = ics * ics - integrated circuits

This relation represents a multiple non-linear regression model with only two quadratic terms added without the cross products or interactions between the independent variables. With respect to the nine products considered in this paper, the earned hours and the predicted earned hours based on this relation is shown in Table 3.

As Table 3 demonstrates, given the numbers of the five main components, we can predict the earned hours for the corresponding product. This procedure is significantly less time consuming and simple.

Concluding Remarks

The main objective of this paper is to develop a simpler and faster way to estimate the laborhour requirements (i.e., the predicted actual hours) for discrete assemblies. To achieve this objective, we first presented the data requirements and regression-based procedures to estimate the earned hours and the actual hours. Next, we showed how the actual hours can be predicted from the earned hours data, and how the earned hours can be predicted from the five main components data. This procedure bypasses the cumbersome and time-consuming allowances and pre-specified times as much as possible and hence results in simpler and faster estimation of the labor-hour requirements.

The procedure in this paper can be enhanced in several different ways. For examples, development of rigorous database and continual updating of the data can increase the relevance of this procedure. Also, as the data on past estimations accumulate, attempts to improve the accuracy of the linear and nonlinear relationships can be of practical value.

Acknowledgment

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Table 3. Comparison of the earned and the Predicted Earned hours

Product	Earned Hours	Predicted Actual Hours
1	2.4260	2.4678
2	0.4328	0.7372
3	0.0936	0.0591
4	0.1175	0.1254
5	0.4960	0.5401
6	0.3603	0.3126
7	0.3996	0.3593
8	1.3511	1.0223
9	0.2311	0.2841

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